COMMAND SYSTEM OF MISSILE GUIDANCE

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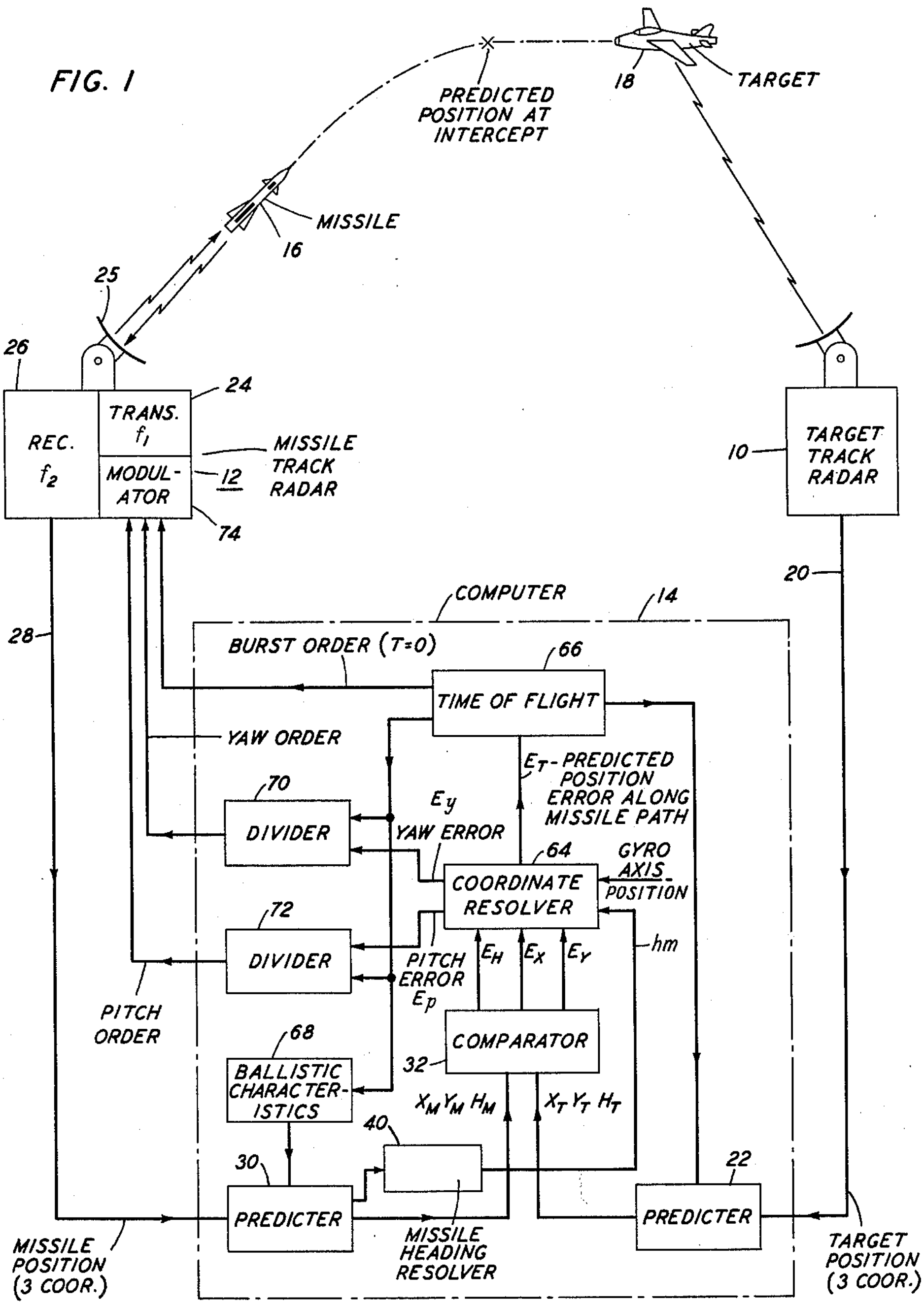
FIG. 1



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COMMAND SYSTEM OF MISSILE GUIDANCE

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FIG. 2

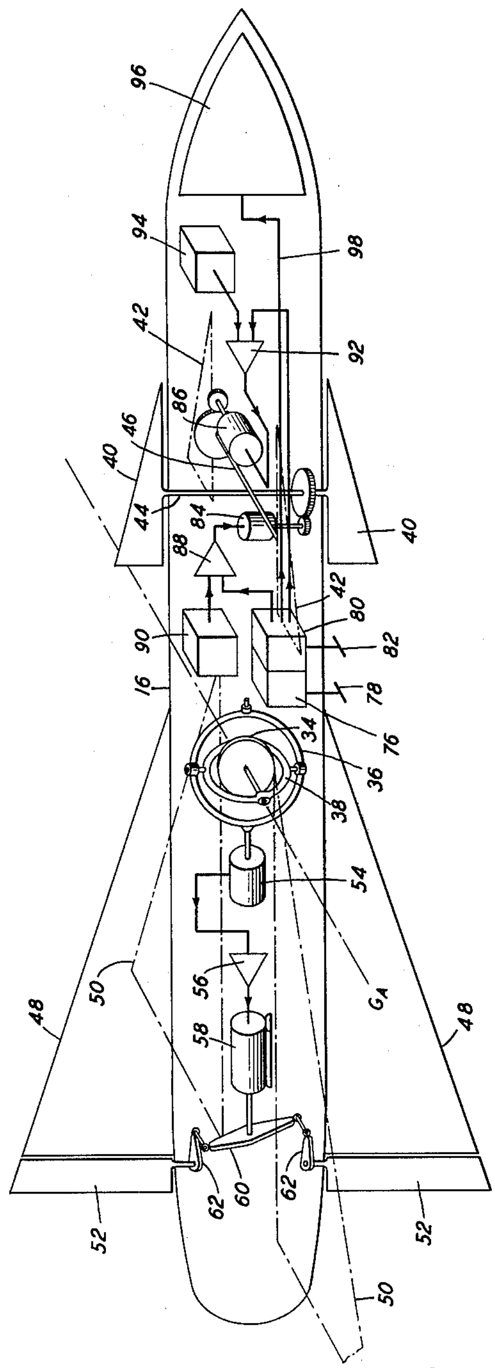

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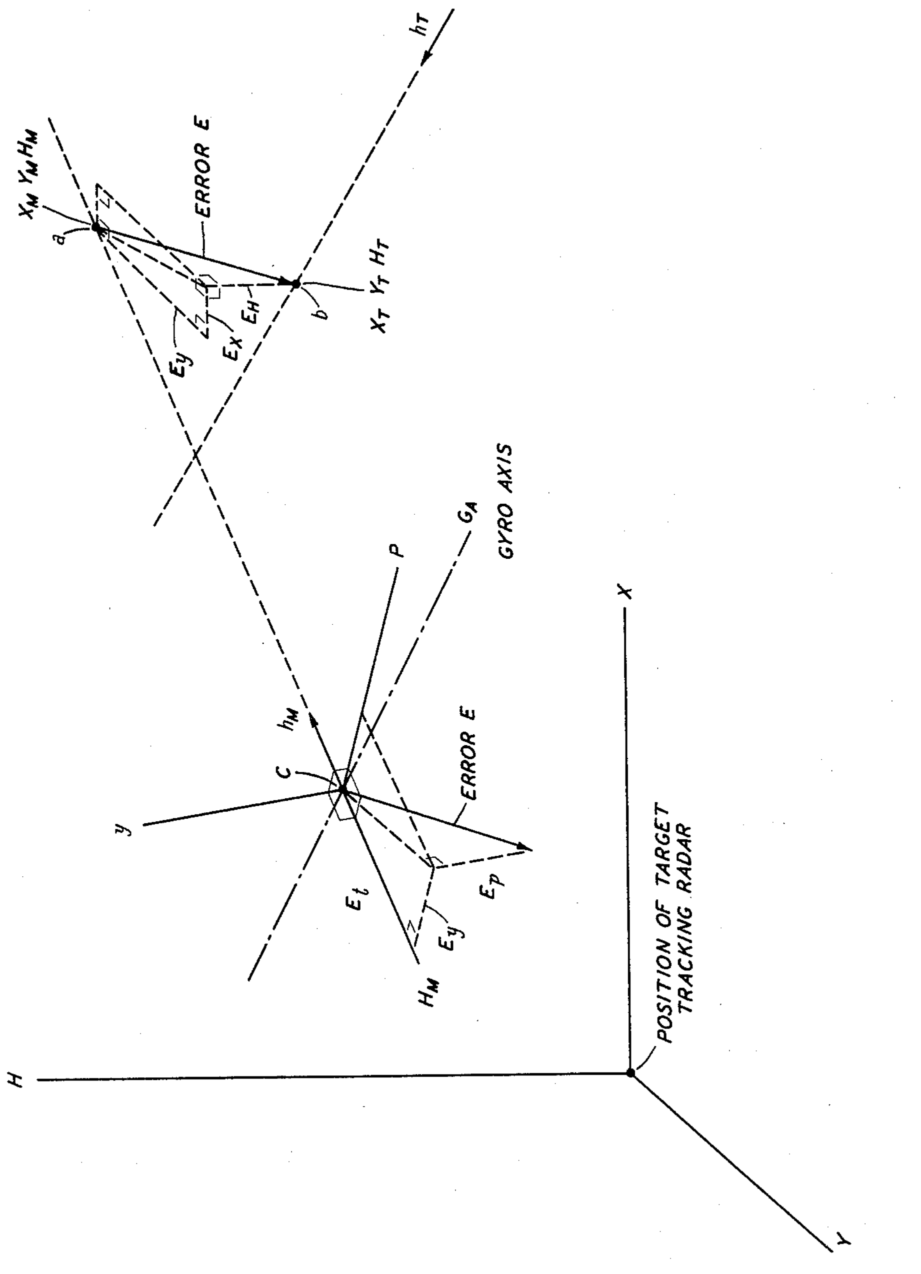
FIG. 3



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COMMAND SYSTEM OF MISSILE GUIDANCE

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This invention relates to guided missile systems and more particularly to systems for the effective control of supersonic antiaircraft missiles.

With the advent of high altitude, high speed bombing aircraft, it has become increasingly difficult to provide an adequate defense with conventional antiaircraft artillery. The extreme ranges at which engagement must occur to prevent a successful bombing attack and the high speeds attained by the aircraft involved result in undesirably long times of flight for even the highest velocity projectiles. The prediction of future position of the target as required by the fire control problem is possible only when it may be assumed that the target course will not change significantly during the flight of the projectile. Obviously this assumption is not valid when long times of flight are involved. As a result it has been proposed to employ missiles which can be steered while in flight as a defense against aircraft targets. The time of flight of the missile is not a critical factor if the missile may be controlled after launching by means responsive to the maneuvers of the aircraft target to insure interception of the target despite evasive action. Such systems necessarily include some means of determining the present position of the target with respect to that of the missile and additional means for computing from this information quantities which may be applied to the steering means and/or to the power plant of the missile to correct its flight so that interception of the target may be accomplished.

Various systems of missile guidance have been proposed. One of the most common of these is that in which the missile is equipped with a homing device. In such systems the missile carries some form of detection apparatus which acts to locate the target and to provide information from which a computing system also carried in the missile may generate suitable control quantities to correct the missile path for interception of the target. Another system involves the so-called beam riding missile wherein a tracking device such as a searchlight or a ground based radar is employed to track the target and the missile is launched in such a way as to intercept the beam. Detection devices aboard the missile respond to the beam and provide inputs for a computer also carried aboard the missile which in turn generates suitable orders thereafter to maintain the missile in the center of the beam.

These and similar systems of missile guidance all suffer from the basic disadvantage that they cause the missile to follow an inefficient trajectory, materially limiting its effectiveness. Further, the complex control system required for guidance must be carried aboard each missile. Since the missiles are necessarily expendable, the cost of such systems becomes almost prohibitive. In addition the presence of extensive control equipment aboard the missile detracts materially from the pay load (usually a warhead) and from the performance and reliability of the missile.

It is an object of the present invention to overcome these disadvantages by minimizing the amount of control equipment which must be carried aboard the missile and at the same time to improve the effectiveness of the antiaircraft system.

In accordance with this object the guided missile system of the present invention employs a missile controlled in accordance with commands issued by a ground based guidance equipment which is capable of operating to a high degree of precision and may be used repeatedly for the control of any number of successive missiles. Both the target and the missile are individually tracked by precision radars and data as to the present position of both are applied to a computer which predicts the future position of the target at a predetermined time (time of intercept) and generates orders for transmission to the missile to control the course thereof in such a way as to insure interception of the target at the predetermined time. Equipment aboard the missile provides a frame of reference traveling with the missile and identifiable at the location of the ground equipment so that proper response to the commands may be obtained.

The above and other features of the invention will be described in detail in the following specification taken in connection with the drawings, in which

FIG. 1 is a block schematic diagram of the complete command missile guidance system of the invention;

FIG. 2 is a diagram in schematic form of the missile employed in the system of FIG. 1 showing the equipment required aboard the missile; and

FIG. 3 is a vector diagram illustrating the missile command problem and the manner in which the orders for transmission to the missile are computed.

In the broadest sense the antiaircraft guided missile system of the invention comprises a target tracking device **10**, a missile tracking device **12**, a computer **14** and a missile **16**, all as shown in the block diagram of FIG. 1. Target tracking device **10** which preferably comprises a precision automatic tracking radar is arranged continuously to provide data as to the present position of a target aircraft **18**. This tracking radar may, for example, be similar to the well known SCR–584 radar which is described in detail in "Electronics" for November 1945 beginning at page 104, for December 1945 beginning at page 104 and for February 1946 beginning at page 110. Briefly this radar is an automatic tracking radar employing conical lobing whereby the radar antenna may be caused continuously to track the target in both elevation and azimuth and to produce electrical representations of these quantities measured with respect to predetermined reference quantities. In addition this radar includes a range unit also responsive to the reflected radar pulses which automatically maintains itself adjusted to represent the slant range to the target.

The output of target tracking radar **10** then comprises three quantities, namely, the slant range from the location of the tracking radar to the target, the azimuth of the target measured from a predetermined direction and the elevation of the target measured from a predetermined reference (normally the horizontal plane). The data units associated with this particular radar vary with the application to be made of the available information. It is assumed for the present purposes that the mechanical shaft positions corresponding to azimuth, range and elevation are converted to electrical quantities for individual transmission over a connector **20** to a predictor **22**. The form in which the target position data are determined is not significant since the means for converting data in one coordinate system to another system are well known in the computer art.

The missile tracking device **12** may be similar to target tracking device **10** and may in the same way produce output quantities proportional to the slant range, the elevation, and the azimuth of the missile as measured at the location of the missile tracking device. As shown in FIG. 1, however, certain advantageous modifications have been made in the missile tracking device to improve the performance thereof. Basically these modifications involve recognition of the fact that the antiaircraft missile

presents an extremely difficult target for a tracking radar. Accordingly it has been found desirable to employ a so-called radar beacon system rather than a conventional radar. For this purpose pulses are radiated from a transmitter **24** at a radio frequency f_1. The missile, as will be explained in greater detail hereinafter, carries a responser which is responsive to pulses of frequency f_1 and radiates pulses of frequency f_2. These pulses are picked up by antenna **25** and directed to a receiver **26** responsive to that radio frequency. The receiver **26** operates in a manner identical to that of target tracking radar **10** to provide the required output quantities for transmission over a connector **28** to a second predictor **30**.

Radar beacon systems of the type contemplated for use in the missile tracking system are well known in the art and are discussed in detail in "Radar Beacons" by Roberts, Vol. 3 of The Radiation Laboratory Series, McGraw-Hill, 1947. Modification of the SCR–584 radar referred to above as illustrative of the ground based missile tracking device for this type of performance may easily be accomplished merely by tuning the receiver to frequency f_2 rather than f_1. The missile-borne equipment will be considered hereinafter.

As assumed above, the quantities applied to predictor **22** indicate the present position of target **18** in spherical coordinates with respect to the location of the target tracking radar while those applied to predictor **30** represent similar information as to the position of the missile with reference to the location of the missile tracking radar. For ease in computation it is considered desirable to convert this information into rectangular coordinates with the origin at the location of the target tracking radar. Such coordinate conversion is well known in the art and may be accomplished as described, for example, in Patent 2,408,081 to Lovell et al., September 24, 1946. Conveniently each predictor **22** and **30** includes a coordinate converter acting to convert input quantities to rectangular coordinates (X, Y and H, where X and Y are orthogonal axes in the horizontal ground plane and H is the vertical distance from the XY plane) with origins at the locations of the respective tracking radars. The necessary offset or parallax corrections required to convert the data as to missile position to the coordinate system having its origin at the location of the target tracking radar may be set in manually as potentials of suitable polarity along the three rectangular coordinates. These corrections are constants and once determined at the time at which the two tracking radars are emplaced, need not be changed unless the emplacement of the guidance equipment is changed.

Computer **14** which includes predictors **22** and **30** acts on the basis of an assumed time of flight for the missile to reach a point of interception with the target. Using this time of flight, the future positions of the target and missile at the predicted time of interception are computed independently. These positions are compared coordinate by coordinate to find the predicted position error at the predicted time of interception. The corrections in either or both the time of flight assumed at the outset and the course of the missile required to insure interception may be determined from this information. Depending upon the nature of the missile either or both of these quantities may be altered to eliminate the position error by the predicted time of interception. This general philosophy of computation is similar in certain respects to that employed in antiaircraft gun direction systems of the type disclosed in the patent referred to above. In the computer herein disclosed, however, many of the operations are duplicated to provide information not only as to the target but also as to the missile since in the present case some measure of control remains after the missile is fired.

Assuming a time of flight, predictors **22** and **30** determine the furture positions of both missile and target at the predicted time of intercept ($T=0$ where T is the time until interception). In each predictor the present position data are differentiated to obtain velocities and these velocities are multiplied by the time of flight to obtain future position. These operations are carried out in each instance in terms of components along the orthogonal X, Y and H coordinates which are ground coordinates with the origin at the location of the target tracking radar as indicated in FIG. 3 of the drawing.

As in the reference patent each predictor **22** and **30** provides three coordinate output data representing the predicted position of the target or the missile as the case may be when the predicted time of intercept occurs. These quantities are identified in FIG. 1 as X_T, Y_T and H_T for the target and X_M, Y_M and H_M for the missile.

These quantities are applied to a comparator **32** in which they are subtracted coordinate by coordinate to obtain predicted position error quantities. The error outputs shown at the output of comparator **32** are E_H showing the position error in the H direction, and E_X and E_Y showing the position errors in the X and Y directions, respectively.

A better understanding of the significance of these quantities may be obtained by reference to the vector diagram of FIG. 3. Here the present heading of the missile is represented by the arrow labeled h_m and that of the target by the arrow h_t. It will be assumed that at the predicted time of intercept ($T=0$) the missile will have reached a position a specified with respect to the X, Y and H axes by the quantities X_M, Y_M and H_M referred to above and the target a position b similarly specified by the quantities X_T, Y_T, and H_T. The total position error at $T=0$ for these assumptions is measured by the vector E, the components of which E_X, E_Y, and E_H in the X, Y, and H direction respectively are as shown in FIG. 3. It is apparent that these quantities are measured with reference to a set of coordinates fixed with respect to the target tracking radar and do not indicate directly what maneuvers must be performed by the missile to assure interception. It is necessary, therefore, to convert these error quantities into quantities measured with respect to a frame of reference traveling with the missile so that appropriate commands for missile guidance may be produced.

The method of providing the required frame of reference traveling with the missile and still identifiable at the location of the guidance equipment will become apparent with reference to the diagram of FIG. 2. Here the missile **16** is shown as carrying a so-called free-free gyroscope **34**, the rotor of which is suspended in a conventional gimbal system. The outer gimbal **36** is journaled for rotation about the longitudinal axis of the missile while the inner gimbal **38** is journaled in the outer gimbal for rotation about an axis normal to the longitudinal axis of the missile. The gyroscope rotor is in turn journaled in the inner gimbal and spins about an axis normal to the inner gimbal axis. This third axis is hereinafter referred to as the gyro spin axis. In accordance with well understood principles the gyroscope acts to maintain the gyro spin axis G_A at a fixed orientation in space regardless of the maneuvers of the missile in which the gyroscope is mounted.

Conveniently, the gyro spin axis is initially oriented in the XY (horizontal) plane and, preferably but not necessarily, normal to the plane of the initial trajectory to the target. This axis and the longitudinal axis of the missile define a reference plane attached to the missile and identifiable at all times at the location of the guidance equipment as will be pointed out below.

The initial orientation of the spin axis may be determined before the missile is launched and the heading (orientation of the longitudinal axis) of the missile at any time may be obtained from the missile velocity vector which is determined as one of the necessary functions of predictor **30**. It will be recalled that the rates of change

of each of the X, Y and H quantities representing the present position of the missile are determined in the prediction process. These components of the missile velocity may be combined to give a quantity proportional to the missile velocity in the direction of the missile flight path. This combination of velocity components is performed by missile heading resolver 40 which is a conventional coordinate resolution device of the type employed generally in fire control computers. It is noted that the frame of reference traveling with the missile is based upon the gyroscope spin axis and the longitudinal axis of the missile while the information available to the computer includes the orientation of the gyro spin axis and the missile velocity. It has been found that, because of the continuous control of the missile afforded by the command system of the invention, the missile velocity vector may be considered to have the same orientation as the longitudinal axis of the missile. Any error so introduced is within the range of correction of the command system. It will be understood, however, that if sufficient information is available as to the aerodynamic performance of the missile, additional computation equipment may be provided to determine the orientation of the longitudinal axis of the missile from the available missile velocity information.

It now becomes necessary to steer the missile with respect to the frame of reference just considered. As shown in FIG. 2 the missile is provided with two sets of paired steering fins 40 and 42, respectively. Fins 40 are mounted on a shaft 44 normal to the longitudinal axis of the missile and fins 42 are mounted on a shaft 46 which is normal to both the longitudinal axis of the missile and the shaft 44. Shafts 44 and 46 thus constitute a pair of steering axes which will be referred to as the yaw and pitch axes, respectively, and which control the orientation of the missile in two orthogonal planes. As a matter of convenience the plane normal to shaft 44 will be referred to as the yaw plane (which is the same as the reference plane considered above) and that normal to shaft 46 as the pitch plane (which includes the longitudinal axis of the missile and is normal to the reference plane). Fins 40 then constitute the yaw steering fins and fins 42 the pitch steering fins. These fins are positioned in response to steering orders transmitted from computer 14 to control the course of the missile after launching.

It is apparent that the course of the missile can be properly controlled only if the steering planes defined above remain properly oriented with respect to the plane of reference considered above and defined by the gyro spin axis and the longitudinal axis of the missile. This condition requires roll stabilization of the missile. For this purpose the missile is equipped with paired cruciform tail fins 48 and 50 and adjustable ailerons 52 are provided upon the trailing edges of at least one pair of tail fins (48 in FIG. 2). Conveniently gyroscope 34 is employed to control ailerons 52 in such a way as to roll stabilize the missile with respect to the reference plane.

The outer gimbal 36 of the gyroscope 34 is coupled to a pick-off or other sensing device 54 through a shaft which forms an extension of the outer gimbal axis. The pick-off or sensing device 54 comprises a source of error signal for a servo system including an amplifier 56, a motor 58 and suitable linkage 60, 62 whereby opposite deflections of upper and lower ailerons 52 may be produced by motor 58. Although these elements, together with the gyroscope 34 which constitutes the error detecting element, may be connected to form any of a large number of known kinds of servo system, it may be assumed for the purposes of the present description that a simple direct current servo system is employed.

For such a servo system pick-off device 54 comprises a potentiometer provided with a center-tapped winding to which direct current potentials are applied from a source such as a battery (not shown to avoid undue complexity in the drawing). The circuit is so arranged that no output is produced when shaft 44 is normal to the reference plane. Whenever the potentiometer arm is moved from this normal (null) position an output is developed, the amplitude and polarity of which are indicative of the amount and direction of the roll of the missile from the desired position. After amplification this output may control motor 58 as in the usual direct-current servo system, causing deflection of the ailerons in the proper direction to return the missile to the desired orientation as indicated by the null output from potentiometer 54.

It will be understood that as a result of such roll stabilization fins 40 are effective to produce steering forces in the yaw plane and the other pair of steering fins 42 act to produce steering forces in the pitch plane. Thus there is provided a set of orthogonal reference coordinates traveling with the missile and comprising the yaw axis y, the pitch axis p and the missile heading h_m. Further the orientation of this reference system in space is continuously determinable at the location of the ground guidance equipment.

It will be recognized that by the usual process of coordinate conversion the total position error E shown in FIG. 3 may be expressed in terms of components along the reference axes traveling with the missile. Such conversion may be accomplished in coordinate resolver 64, FIG. 1 as outlined beginning page 279 of "Electronic Analog Computers" by Korn and Korn, or in Patent 2,658,674 to Darlington et al., November 10, 1953, particularly in FIG. 38 and the specification beginning at column 92 thereof. This coordinate resolver accepts the three position error components E_H, E_X and E_Y shown in FIG. 3 and in addition accepts quantities from the output of missile heading resolver 40 indicating the orientation of missile heading axis in space and quantities representing the positon of the gyro spin axis G_a which may be set into the coordinate resolver as constants. The outputs of coordinate resolver 64 are E_y and E_p representing position errors in the yaw and pitch planes and measured along the pitch and yaw axes respectively and E_t representing a position error along the missile path. These components are shown in FIG. 3 with respect to the missile axes p, y and h_m (drawn with an origin at point c, the present position of the missile).

E_t, the predicted position error along the missile path is a measure of the adjustment which must be made in the time of flight (or the speed) of the missile to cause interception of the target. If it be assumed that the speed of the missile is not subject to external control once the missile is launched, this correction must be made by varying the time of flight originally assumed at the outset of the computation process and employed as one input to each of predictors 22 and 30. This quantity is, therefore, applied to a time of flight servo mechanism 66 and controls the setting of input quantities applied to the two predictors possibly as a shaft rotation as in the predictors shown in Patent 2,408,081, referred to above. Since the speed of the target is assumed to be constant, the quantity controlling predictor 22 is applied directly thereto. However, the corresponding quantity for predictor 30 which is associated with the missile section of the computer is modified in accordance with the ballistic characteristics of the missile before application to predictor 30. Such modifications are accomplished by apparatus 68 wherein appropriate changes are made in the value of time of flight. These changes are ordinarily accomplished by adding both fixed and variable components to that corresponding to the time of flight as shown for example in FIG. 8A of Patent 2,408,081 to which refererence has been made above.

It will be understood from the above that the necessary functions for the continous prediction process performed by the computer are provided by way of the time of flight servo mechanism and the target and missile tracking radars. The pitch and yaw error outputs E_y and E_p from

coordinate resolver **64** are employed for the generation of steering orders for the missile. These quantities depend of course upon the time of flight fed back to predictors **22** and **30** as discussed above. As a matter of convenience in control of the missile it has been found desirable to convert these position orders into acceleration orders, i.e. the quantities representing the position errors measured along the yaw and pitch axes are converted into lateral accelerations in the pitch and yaw planes, respectively, such that the missile will be at the point of predicted interception at the predicted time of interception. For the generation of such orders the quantities E_y and E_p are applied respectively to dividers **70** and **72** in which each is divided twice by the time of flight produced as the output of unit **66**. The yaw and pitch orders appearing at the outputs of dividers **70** and **72** respectively are thus proportional to the accelerations required to cause the missile to reach the predicted point of interception at the predicted time of interception. These orders may be transmitted to the missile by any convenient means, for example, by a high frequency radio communication channel.

Alternatively and as shown in FIG. 1, the acceleration orders for the missile are transmitted by modulation of the repetition rate of the missile tracking pulse transmitter. The necessary control quantities may be transmitted on a time division basis or any other convenient basis by the action of a modulator **74** associated with transmitter **24**. Various systems of signaling over the radar beam are described in Section 11.2 of "Radar Beacons," vol. 3 of the "Radiation Laboratories Series." According to one such system the two control signals are transmitted as audio frequency signals frequency modulated upon the pulses from the track transmitter. Either one or both of the frequencies can thus be transmitted depending upon the steering orders required at a particular time, the modulating wave comprising either one or the sum of the audio frequencies.

Also transmitted to the missile and conveniently by interruption of all modulation upon the radar beam is the so-called burst order which at a time related to the predicted time of intercept causes the warhead of the missile to explode. Ordinarily this order is transmitted a few microseconds prior to the time when $T=0$.

The remaining equipment carried aboard the missile may now be considered. As has been stated above the missile carries a transponder responsive to pulses from the ground based missile tracking equipment. This transponder includes a receiver **76** tuned to frequency f_1 associated with antenna **78**, and a microwave pulse transmitter **80** which is triggered by the output of receiver **76** and which radiates pulses of frequency f_2 from antenna **82**. These pulses when received at the location of the guidance equipment permit tracking of the missile.

Radio receiver **76** also serves to receive the various orders transmitted from the guidance equipment and intended to control the steering fins of the missile and the bursting of the warhead at appropriate times. Accordingly it is provided with demodulation and channel separating equipment appropriate to the nature of the modulation and multiplex systems employed to transmit these orders. In any event the receiver is designed with reference to the particular transmitter **24**, FIG. 1, employed in the guidance equipment and produces three output signals corresponding respectively to the pitch and yaw acceleration orders and the warhead burst order.

As shown in FIG. 2, each pair of missile steering fins is driven by a servo motor, in response to the appropriate orders occurring at the output of receiver **76**. Thus a motor **84** is geared to the shaft **44** upon which steering fins **40** are mounted and a motor **86** is geared to the corresponding shaft **46** upon which steering fins **42** are mounted. It will be recalled that the missile is to be made responsive to acceleration orders. Accordingly for each set of steering fins the appropriate order appearing at the output of radio receiver **76** is applied to an amplifier to which is also applied an output of an accelerometer. These two quantities are applied in opposition and the motor is driven from the output of the amplifier until the accelerometer indicates that the desired lateral acceleration has been introduced. When such a condition occurs the output of the amplifier is reduced to zero and the motor stops. If the lateral acceleration increases, the output of the accelerometer exceeds the order output of the receiver and the motor is driven in the appropriate direction to return the acceleration to the required value. The yaw steering fins **40** are thus controlled by the output of the comparison amplifier **88** to which is applied the output of an accelerometer **90** oriented in the missile to indicate accelerations in the yaw plane. Similarly the pitch steering fins **42** are controlled by a comparison amplifier **92** to which is applied the pitch order output of the receiver and the output of an accelerometer **94** oriented in the missile to detect accelerations in the pitch plane.

The remaining equipment in the missile includes a warhead **96** furnished with an appropriate detonator which may be actuated by an electric impulse known as the burst order received from the appropriate output of receiver **76** and applied to the warhead over lead **98**.

In summary, the command system of missile guidance according to the invention minimizes the amount and the cost of the equipment which travels with the missile and is expended with each missile and places the majority of the precision control equipment on the ground where it can be used repeatedly and where adequately controlled environment for maximum efficiency of operation can be provided. In the operation of the system, a target is tracked by the target tracking radar and when the computer circuits have had time to settle and the predicted point of interception is within range of capability of the missile, a missile is launched. As the missile is launched it is tracked by the missile tracking equipment and the computer continuously determines corrections to be made in the missile course to insure interception of the target at a predicted time of interception. So long as the lateral accelerations of which the missile is capable in the course of maneuvers exceed those of the target aircraft, interception of the target can be accomplished regardless of evasive maneuvers attempted thereby. When the predicted time of interception approaches, the computer produces a burst order which actuates the warhead of the missile at such a time as to insure the maximum effectiveness against the target of the resulting detonation.

What is claimed is:

1. In an antiaircraft system a missile, means in said missile for establishing a reference axis of fixed orientation with respect to the earth, means for steering said missile about a pair of orthogonal axes fixed with respect to the missile, means for stabilizing said missile to maintain one of said steering axes normal at all times to the plane defined by said reference axis and the longitudinal axis of the missile, tracking means for continuously establishing the position of a target aircraft in space, other tracking means for similarly establishing the position of said missile, means for computing from the target and missile positions a predicted path for said target and a predicted missile path intercepting the target at a future time and means for transmitting control signals based on said predicted paths to the missile steering means to insure interception of the target by the missile at said time.

2. In an antiaircraft system a missile, means in said missile for producing lateral accelerations thereof in a pair of orthogonal acceleration planes fixed with respect to said missile and intersecting in a line coincident with the longitudinal axis of said missile, means aboard said missile for establishing a reference axis of fixed orientation with respect to the earth, means for maintaining said acceleration planes in fixed relationship to the reference plane defined by said reference axis and the

longitudinal axis of said missile, means for continuously establishing the present positions of said missile and a target aircraft in space, means for computing from said present positions and an assumed future time of interception corrections in the course of said missile to insure interception of the target at said time and means for transmitting orders from said computer to said acceleration producing means in said missile correspondingly to produce lateral accelerations in said acceleration planes to correct the missile course for interception of the target at said time.

3. In an antiaircraft system a self-propelled missile, a gyroscope mounted in a gimbal system in said missile with the outer gimbal axis coincident with the longitudinal axis of said missile, means for steering said missile about a pair of axes normal to the longitudinal axis of the missile and initially having a predetermined positional relationship to the reference plane defined by said longitudinal axis and the spin axis of said gyroscope, means responsive to rotation of the outer gimbal with respect to said steering axes to rotate the missile about its longitudinal axis for the purpose of maintaining said initial relationship, means for continuously establishing the positions of said missile and of a target aircraft in space, means for computing from said positions future positions of said missile and said target aircraft and a course for said missile to insure interception of the target aircraft at a future time and means for transmitting control signals dependent upon the predicted missile course to said steering means.

4. In an antiaircraft system a missile, means in said missile for establishing a reference axis of fixed orientation with respect to the earth, means for steering said missile about a pair of axes fixed with respect to said missile and normal to the longitudinal axis thereof, ailerons for controlling the roll of the missile about said longitudinal axis, means for sensing rotation of the missile about said longitudinal axis with respect to said reference axis, means responsive to said sensing means for deflecting said ailerons to return the steering axes to a predetermined relationship with respect to a reference plane defined by said longitudinal and reference axes, means at a ground control station for determining from the present positions of said missile and of a target aircraft, means for determining from said present positions a missile course to insure interception of said target aircraft, and means for transmitting orders from said ground station to said missile to produce maneuvers of missile about said steering axes to maintain the course to interception of said target.

5. In an antiaircraft system a self-propelled missile, means for tracking a target and producing quantities representative of its position in rectangular earth coordinates having their origin at the location of said tracking means, missile tracking means producing output quantities representative of the position of said missile in said earth coordinates, means in said missile for establishing a reference axis of fixed orientation with respect to said earth coordinates, steering means aboard said missile for producing lateral accelerations thereof in orthogonal planes bearing a fixed relationship to said missile, means for roll stabilizing said missile to maintain said acceleration planes in fixed relationship to said reference plane, means for computing from the positions of said missile and said target in said earth coordinates corrections in the course of said missile required to insure interception of said target by the missile at a future time, means for converting said course corrections into acceleration orders related to said reference plane aboard the missile and means for transmitting said orders to said missile to control lateral accelerations thereof in said acceleration planes.

6. In an antiaircraft system a self-propelled missile, means in said missile for establishing a reference axis of fixed orientation with respect to the earth, means for producing lateral accelerations of the missile in a pair of acceleration planes intersecting along the longitudinal axis of the missile, means for stabilizing the missile to maintain a fixed relationship between said acceleration planes and the reference plane defined by said reference axis and the longitudinal axis of the missile tracking means for continuously establishing the position of a target in space, other tracking means for similarly establishing the position of said missile, means for computing from the target and missile position information position errors at a predicted time of interception as measured in said reference plane and said acceleration planes aboard the missile, means for converting said errors into accelerations of the missile required to eliminate the errors by the predicted time of interception, and means for transmitting orders representing said accelerations to said lateral acceleration producing means aboard the missile to correct the course thereof.

7. In an antiaircraft system a missile, means in said missile for establishing a reference axis of fixed orientation with respect to the earth, means for steering said missile about a pair of axes fixed with respect to the missile, means for stabilizing the missile to maintain said steering axes in fixed relationship at all times to the plane defined by said reference axis and the longitudinal axis of the missile, means for determining the present positions of said missile and of a target, means for predicting from the present position of said target the position thereof at a chosen time of interception, means for predicting from the present position of said missile and the ballistic characteristics of the missile the position of the missile at said time, means for determining from said predicted positions a position error in components along a set of axes including the longitudinal axis of said missile and said steering axes, and means for producing from at least some of said position error components control signals for transmission to said missile steering means to eliminate said position errors by said time.

8. In an antiaircraft system a self-propelled missile, means in said missile for establishing a reference axis of fixed orientation with respect to the earth, means for producing lateral accelerations of the missile in a pair of acceleration planes intersecting along the longitudinal axis of said missile, means for stabilizing said missile to maintain said acceleration planes in fixed relationship to the reference plane defined by said reference axis and the longitudinal axis of said missile, ground based means for determining from quantities continuously representative of the present positions of said missile and of a target the relative positions thereof at a predetermined time of interception, means responsive to the relative positions at said predetermined time to obtain position errors in terms of earth coordinates having an origin at the location of said ground based means, means for converting said position errors in earth coordinates to corresponding errors in terms of a reference system based upon said reference and said acceleration planes and traveling with said missile, means for determining from said corresponding errors the requisite accelerations in said acceleration planes to eliminate said errors at said predetermined time of interception, and means for transmitting signals proportional to said accelerations to said missile to control said missile steering means to produce such accelerations.

9. In an antiaircraft system a self-propelled missile, a warhead in said missile and detonating means therefor, means also in said missile for establishing a reference axis of fixed orientation with respect to the earth, means for steering said missile about a pair of axes fixed with respect to said missile, means for stabilizing said missile to maintain one of said steering axes normal at all times to the plane defined by said reference axis and the longitudinal axis of said missile, means for continuously establishing the positions of said missile and of a target in space, means for computing from said missile and target position information a predicted path for said missile to insure interception of the target at a future time, means for transmitting control signals dependent upon the pre-

dicted missile path to said missile steering means and means for transmitting a control signal to said detonating means at said future time of interception.

10. In an antiaircraft system a self-propelled missile having a warhead and detonating means therefor, means aboard said missile for establishing a reference axis of fixed orientation with respect to the earth, means for steering said missile with respect to a set of rectangular coordinates, including the longitudinal axis of the missile and an axis perpendicular to the plane defined by said reference axis and the longitudinal axis of said missile, tracking means for continuously establishing the present positions of said missile and of a target aircraft, means for predicting from said present positions the positions of said missile and said aircraft at a predetermined time of interception, means for producing position error quantities with respect to the reference coordinates traveling with said missile, means aboard the missile and responsive to said transmitted quantities effective to change the missile course to reduce the position errors substantially to zero at said time, and means operative at said time to transmit an actuating signal to said warhead detonating means.

11. In an antiaircraft system a missile, a gyroscope mounted in said missile in a gimbal suspension having inner and outer gimbal axes, means for supporting the outer gimbal axis in coincidence with the longitudinal axis of said missile, a potentiometer fixed in said missile and driven by relative rotation of said outer gimbal and said missile to sense roll of the missile about its longitudinal axis, ailerons mounted on said missile to control rotations thereof about said longitudinal axis, a servo system including said potentiometer as a sensing element and driving said ailerons to maintain a fixed angular relationship between said outer gimbal and the missile, a pair of steering axes on said missile normal to said longitudinal axis, steering fins on said axes and means responsive to orders from a ground based computer accepting the present positions of said missile and of a target and information as to the orientation of the gyroscope spin axis to actuate said fins for guiding said missile to interception with said target.

12. In an antiaircraft system a missile, means in said missile for producing lateral accelerations thereof in a pair of orthogonal planes fixed with respect to said missile and intersecting in a line coincident with the longitudinal axis of said missile, means aboard said missile for establishing a reference axis of fixed orientation with respect to the earth, means for maintaining said planes in fixed relationship to the reference plane defined by said reference axis and the longitudinal axis of said missile, means for continuously establishing the present positions of said missile and a target aircraft in space, means for computing from said present positions and an assumed future time of interception the lateral accelerations of the missile in said orthogonal planes to insure interception of the target at said time, means for transmitting control quantities proportional to said accelerations to said missile, means aboard the missile for determining the lateral accelerations in said orthogonal planes, means for comparing the transmitted acceleration quantity for each of said planes with the measured acceleration in the respective plane, and means for adjusting the corresponding acceleration producing means aboard said missile to bring to equality the transmitted acceleration quantity and the measured acceleration for each of said planes.

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